C-AFM and KPFM Characterization of poly-Si/SiOx/c-Si Passivated Contact Structure

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ABSTRACT:
Poly-Si/SiO_x/c-Si structures were characterized using conductive AFM (C-AFM) and Kelvin Probe Force Microscopy (KPFM) techniques with the objective to provide a better understanding of the structure, and notably the presence of nanoholes in the oxide. The observed samples include highly doped poly-Si layers annealed at different temperatures (700, 800 and 900 °C) and also intrinsic poly-Si layers. The latter layers have been in particular implemented to facilitate C-AFM and KPFM correlative analysis on the same scan areas. It is found that the C-AFM technique is not conclusive due to the high doping and surface morphology of the poly-Si layer. On the other hand KPFM allows to observe local surface potential drops that may be correlated to holes in the oxide. Correlative microscopy measurements applied on intrinsic poly-Si allowed to evidence links between C-AFM and KPFM observations, however surface conduction effects on c-AFM still remain.
Keywords: Photovoltaics, KPFM, c-AFM, pinhole, Diffusion

1 INTRODUCTION

The laboratory record efficiencies of single junction solar cells are getting closer and closer to the theoretical limit. The remaining losses in solar cells are mostly due to recombination at interfaces [1]. At the level of contacts, several approaches are currently investigated to minimize the recombination, among which the passivated contact represents one of the most promising concept. This concept uses a thin SiO_x layer between a heavily doped polysilicon film (poly-Si) and a crystalline silicon (c-Si) absorber [2, 3].

The conduction mechanisms taking place across this structure are the tunnelling current through the SiO_x and/or an electrical current driven by nanoholes in the oxide named pinholes [4]. These pinholes were indeed revealed on samples fabricated by LPCVD using a selective wet etching method based on a tetramethylammonium hydroxide (TMAH) solution [5].

In this study we focus on local electrical measurements based on an Atomic Force Microscopy (AFM) set-up to investigate PECVD grown highly doped poly-Si/SiO_x and intrinsic poly-Si/SiO_x contact structures [6], and notably the presence of pinholes depending on the annealing temperature. To this purpose electrical analyses were performed by conductive AFM (C-AFM) and Kelvin probe AFM (KPFM) on top of the previous structures.

2 EXPERIMENTAL

In this study, n type CZ c-Si wafers with thickness of 275 µm were chosen. A wet chemical cleaning by hydrofluoric acid (HF) followed by a chemical oxidation using ozonized DI-H2O was performed to grow a thin SiO_2 layer of 1.3 nm. After this hydrogen-rich a-Si layer was deposed by PECVD along two case of with or without boron doping. Afterward a high temperature annealing was performed to obtain the poly-Si/SiO_x/c-Si structures with either a highly p-doped or an intrinsic poly-Si layer. We have then performed C-AFM and KPFM measurements with the objective to provide a better understanding of the structure, and notably the presence of pinholes in the oxide. In particular, the KPFM technique was directly applied on the previous structures without using a selective wet etching process. Lastly, the implementation of intrinsic poly-Si on the passivated contact structure has been used here to minimize the lateral conduction and facilitate C-AFM and KPFM correlative analysis on the same scan areas.

3 RESULTS AND DISCUSSION

3.1 C-AFM characterization

C-AFM measurements were performed on the structures with highly doped poly-Si layer annealed at 800°C after surface deoxidation by a HF treatment. Measurements were first done on a sample with the buffer passivating oxide layer (Fig.1.a) and then on a sample structure without passivating oxide between the poly-Si layer and the c-Si wafer. In the current maps of both structures, current spots (CSs) in the order of a few nanoamperes (nA) were observed, pointing out densities which are comparable to those observed by Lancaster et al. [7]. However the CS pattern is observed for both configurations, which suggests that C-AFM maps are not mirroring the spatial distribution of pinholes. This is because several properties of the poly-Si (surface morphology, doping, lateral conduction…) can be convoluted in the C-AFM image. In addition, when comparing the density of CSs (250-750 μm^{-2}) with the density of pinholes revealed by selective wet etching (in the range of 10^{-2} to 1 μm^{-2}) [5], the measured CS density is several orders of magnitude higher. C-AFM measurements performed on highly conductive poly-Si layers thus appear to overestimate the pinholes density in the oxide. Similar conclusions are presented by Richter et al. [8] where no correlation was found between the c-AFM results, treated by vertical current path counter, and the selective wet etching previously mentioned.

3.2 KPFM measurements

Those measurements are based on the study of Kales et al. [9] which performed KPFM measurements on passivating contact structures after a TMAH/HF treatment to remove the poly-Si and the SiO_x layer underneath. In our approach, we performed the KPFM measurements directly on the poly-Si layer without removing any layer. However, as for the c-AFM measurements, an HF treatment was required to deoxidize the poly-Si surface.

KPFM measurements were carried out on the same samples that were analyzed by C-AFM and illustrated in Fig. 1. Both samples have highly doped poly-Si layers resulting from an annealing at 800°C, but one them has no passivating oxide at the poly-Si/c-Si interface.

The scan displayed in Fig. 2.a, obtained on the sample with interfacial SiO_x, shows local drops of the surface potential with surface density values in the range of 10^{-1} to $1\mu m^{-2}$. The second scan (Fig 2.b), illustrates the KPFM image performed on the sample without SiO_x. In this case the map appears homogeneous without observable change in surface potential.

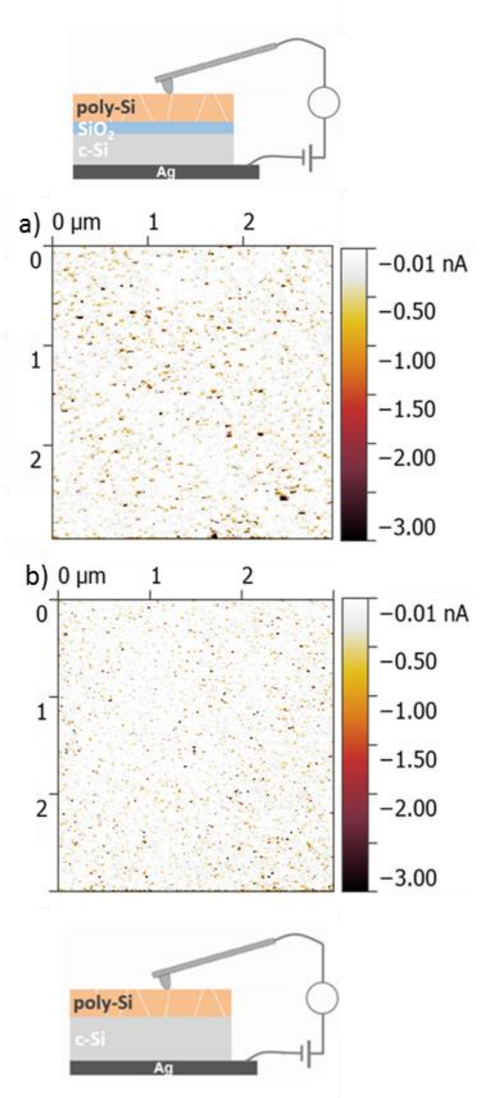

Figure 1: c-AFM scans on: a) poly-Si/SiO_x/c-Si structure with interfacial oxide and b) poly-Si/c-Si structure without interfacial oxide.

By comparing those two results it appears that the observed potential drops are directly linked to the presence of the oxide buffer underneath the poly-Si layer. Therefore we linked those potential drops to local doping level drops caused by higher diffusion during annealing at the position of pinholes, in agreement with conclusions of Kale et al. [9].

It is to be noted that similar KPFM measurements performed on a sample from ISFH institute with poly-Si layer grown by LPCVD gave the same results. Those measurements are not shown here.

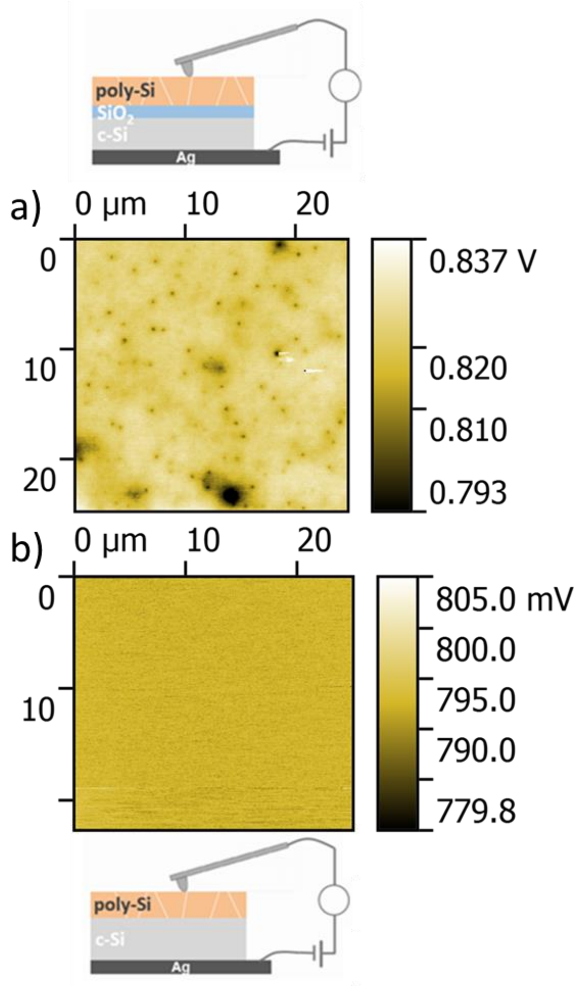

Figure 2: KPFM scans on: a) poly-Si/SiO_x/c-Si structure with interfacial oxide and b) poly-Si/c-Si structure without interfacial oxide.

3.3 KPFM and c-AFM measurements on passivated contact with intrinsic poly-Si layer

Low doping levels in the poly-Si layer seems to be a requirement to minimize the lateral conduction properties that can greatly impact the understanding of C-AFM measurements. Consequently, an intrinsic poly-Si/SiO_x/c-Si structure was analyzed by KPFM and C-AFM on the same area. Correlative analysis of both scans show similar features: local drops of the surface potential in KPFM can be localized as current peaks in C-AFM. These common features measured in the same area are highlighted by circles in Fig. 3. However, these similarities concern only a small part of the numerous current spots that are observed by C-AFM.

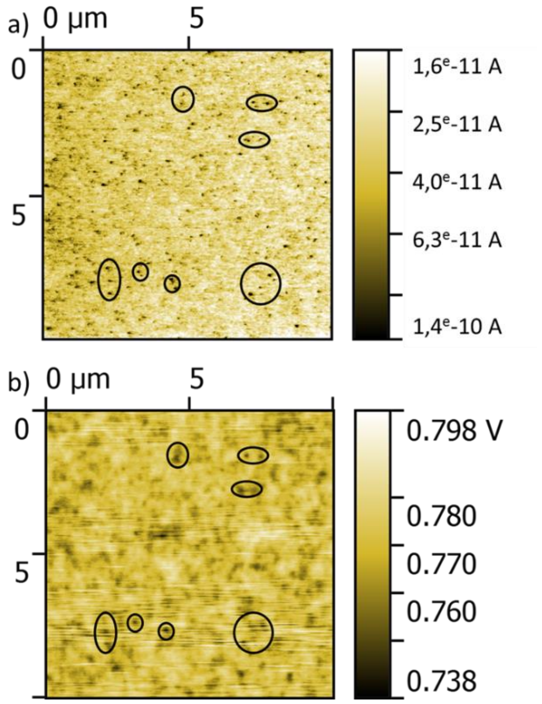

Figure 3: a) c-AFM and b) KPFM measurements on the same area of a (i)poly-Si/SiO_x/c-Si sample

4 CONCLUSION

We have shown results of c-AFM and KPFM measurements on samples with a PECVD grown poly-Si layer on top of an ozonized DI-H_2O wet rinsing grown SiO_x layer. The current maps obtained from c-AFM exhibit current spots resulting mainly from the poly-Si layer structure and high doping level, which are not directly related to properties of the buffer SiO_x layer. The KPFM technique allows observation of local potential drops without the need to etch the passivated junction. Those local drops are expected to be an indirect observation of the pinholes through which the dopant diffusion is favored during the annealing process. The C-AFM and KPFM cross-check analysis performed on an intrinsic poly-Si/SiO_x/c-Si structure shows that only a small part of the current spots are correlated with local potential drop spots. It is concluded that the surface morphology, microstructure and conduction properties of the poly-Si layer itself strongly influences the C-AFM measurements and can produce local current spots that are not related to pinholes in the SiO_x buffer layer. As a consequence, attributing these current spots to pinholes leads to an overestimation of their density.

4 ACKNOWLEDGMENTS

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5 REFERENCES

[1] D. Adachi et al., *Impact of carrier recombination on fill factor for large area heterojunction crystalline silicon solar cell with 25.1% efficiency*, Appl. Phys. Lett. 107, 233506 (2015), doi: 10.1063/1.4937224

[2] F. Feldmann et al., *Tunnel oxide passivated contacts as an alternative to partial rear contacts*, Sol. Ener. Mat. Sol. Cells, (2014), doi: 10.1016/j.solmat.2014.06.015

[3] A. Richter et al., *Tunnel oxide passivating electron contacts as full-area rear emitter of high-efficiency p-type silicon solar cells*, EUPVSEC paper (2017), doi : 10.1002/pip.2960

[4] F. Feldmann et al., *Charge carrier transport mechanisms of passivating contacts studied by temperature-dependent J-V measurements*, Sol. Ener. Mat. Sol. Cells 178, (2018) doi: 10.1016/j.solmat.2018.01.008

[5] T. F. Wietler et al., *Pinhole density and contact resistivity of carrier selective junctions with polycrystalline silicon on oxide*, Appl. Phys. Lett. 110, 253902 (2017), doi: 10.1063/1.4986924

[6] A. Morisset et al., *Improvement of the conductivity and surface passivation properties of boron-doped poly-silicon on oxide*, AIP Conference Proceedings 1999, 040017 (2018), doi: 10.1063/1.5049280

[7] K. Lancaster et al., *Study of Pinhole Conductivity at Passivated Carrier-selected Contacts of Silicon Solar Cells*, Energy procedia 92, (2016) 116-121, doi: 10.1016/j.egypro.2016.07.040

[8] S. Richter et al., *Evaluation of localized vertical current formation in carrier selective passivation layers of silicon solar cells by conductive AFM*, AIP Conference Proceedings 2147, 040017 (2019), doi : 10.1063/1.5123844

[9] A. Kale et al., *Tunneling or Pinholes: Understanding the Transport Mechanisms in SiOx Based Passivated Contacts for High-Efficiency Silicon Solar Cells*, 7th World Conference on Photovoltaic Energy Conversion, At Waikoloa, Hawaii (2018), doi: 10.1109/PVSC.2018.8547211